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RELATIONSHIP BETWEEN RECOGNITION RANGE
AND THE SIZE, ASPECT ANGLE, AND COLOR OF
AIRCRAFT

Robert D. Baldwin

Human Resources Research Organization

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Relationship Between Recognition Range and the Size, Aspect Angle, and Color of Aircraft

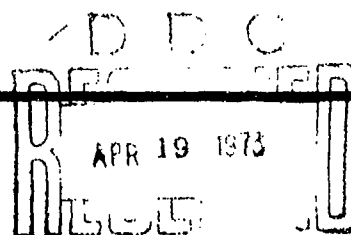
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13. ABSTRACT <p>Reduced-scale field tests were conducted using 1/72nd scale model aircraft to estimate the relationship between aircraft size (presented area) and recognition range by ground observers equipped with binoculars. The overall size, color, and aspect angle (view) of the models were varied. The observers were highly trained and well-motivated members of the military and civilian research staff. The average recognition ranges and accuracy levels obtained far exceeded previously published data, being in the realm of detection ranges. The dark grey models having a reflectance similar to camouflaged aircraft were recognized 1900 meters (full-scale) sooner than aluminum-colored models. Aspect angles affected recognition range, as did overall size. Trial-to-trial reliability was high for each view, but there was little consistency in the recognition ranges between different views.</p> <p>Details of illustrations in this document may be better studied on microfiche</p>		

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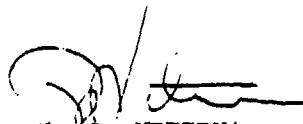
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1. The report presents results of tests conducted to obtain information on the abilities of human observers to identify low-flying aircraft. These data are needed in planning for future air defense weapon systems.
2. Models of 13 representative jet-powered aircraft were used in reduced-scale field testing, to determine the distance at which aircraft in six aspect angles could be recognized, to evaluate the reliability and consistency of observers, and to assess the effect of aircraft color on recognition range. The average recognition ranges obtained in the tests far exceeded any previously reported, and were comparable to aircraft detection ranges. The head-on view presented the greatest difficulty for observers. Grey-painted models with the light reflectance of aircraft painted in terrain camouflage colors were recognized sooner than silver-painted models with the same reflectance as aluminum. Observers with equal training and experience appeared to use the same recognition cues.
3. This report will be of particular interest to those engaged in development of detection models and simulations of air defense engagements for purposes of war gaming, training, or weapon system development.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:


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HumRRO
Technical
Report
73-2

Relationship Between Recognition Range and the Size, Aspect Angle, and Color of Aircraft

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Fort Bliss, Texas

HUMAN RESOURCES RESEARCH ORGANIZATION

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FOREWORD

In February 1971, the U.S. Army Combat Developments Command Air Defense Agency requested that the Human Resources Research Organization provide information concerning the relationship that tends to exist between the size of an aircraft and its recognition range. This report presents the results of tests conducted to satisfy that request. The research was performed as a Technical Advisory Service related to Work Unit SKYFIRE, Training Methods for Forward Area Air Defense Weapons, by HumRRO Division No. 5, Fort Bliss, Texas, with Dr. Albert L. Kubala as Director. Military research support was provided by the U.S. Army Air Defense Human Research Unit, LTC Frank R. Husted, Unit Chief.

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Meredith P. Crawford
President
Human Resources Research Organization

PROBLEM

The U.S. Army Combat Developments Command, Air Defense Agency conducts computer simulations to establish requirements and characteristics of future air defense (AD) weapon systems. Some forward area AD systems depend upon human ability to establish the identity of the aircraft. A number of field and reduced-scale tests have been conducted to obtain estimates of the distances at which low-flying aircraft can be recognized. None of these previous tests, however, has related recognition range to the size and aspect angle of the aircraft. These types of data were needed by the Air Defense Agency in order to accomplish more valid simulations of air defense engagements.

RESEARCH OBJECTIVES

The primary objective of the tests described in this report was to obtain estimates of the average distance at which each of 13 representative attack aircraft could be recognized for each of six aspect angles (or views). A secondary objective was to evaluate man's consistency or reliability in making such judgments. That is, how much variability is there within an individual and between different individuals? A third objective, evolved during the conduct of this research, was concerned with evaluating the effect of aircraft color (or light reflectance) upon recognition range.

RESEARCH METHOD

Thirteen aircraft, judged by the senior researcher to be representative of jet-powered attack aircraft with respect to sizes and structural configurations, were selected for the experiment. They consisted of the following types:

Single Engined: MiG-15, AF-1E, F-84, F-100, Fitter, MiG-21, Mirage, and F-102.

Multi-Engined: B-57, B-66, Flashlight, Firebar, and Beagle.

Models of these aircraft were available in 1/72nd scale for conducting reduced-scale field testing.

The size of the aircraft was estimated in terms of the area presented in square feet for each of the six views. These measurements were estimated by photographing each model at each aspect and then projecting the views against graph paper. After the scale factor was correctly established, the outline of the image was traced, and the area was computed.

In this reduced-scale field testing, each model was moved toward four observers equipped with 7-power binoculars, and the distance at which each observer correctly recognized the aircraft model was determined. Separate testing was done for each view. Each of the models was presented 10 times in random order for each view.

All testing was conducted outdoors using natural sky backgrounds. In most of the testing, the models used were painted dark grey. The grey color had a light reflectance comparable to that of an aircraft painted in camouflage colors. Supplementary testing was conducted using silver colored as well as dark grey models.

RESULTS

Recognition Range. The average recognition range varied from 6.0 kilometers for the Mirage at a head-on view (0° climb- 0° heading) to 14.7 kilometers for the B-57 at a 45° climb- 35° heading. The head-on view tended to present the most difficult task for the observers. Complete tables of the recognition ranges for each aircraft and each view are presented in the body of this report and in the Appendix.

The supplementary testing comparing silver and dark grey models, which used six aircraft at the 15° climb- 45° heading, showed that, averaged over all aircraft, the grey models were recognized about 1.9 kilometers sooner than their silver counterparts.

The relationship between recognition range and the area presented by the aircraft was determined by means of correlation techniques for each of the six views. This analysis showed that only 25 to 50% of the variability in recognition ranges could be predicted from area for five of the six views. The correlation coefficient for the sixth view, 15° climb- 45° heading, was not large enough to be statistically significant. Apparently, the area presented by an aircraft is not the main determinant of the recognition range.

Aircraft Size. The area presented by the aircraft ranged from a low of 38 square feet for the MiG-21 in a head-on view to 976 square feet for the B-66 at a 45° climb- 35° heading. The relationships between area presented for each view and linear measures of the aircraft were also computed. As would be expected, the correlation coefficients were quite high. The linear regression equations for predicting area from length and wing span are presented in this report. Also included is a table presenting the aircrafts' geometric sizes expressed in square miles at the mean recognition range.

Recognition Accuracy. During these tests, the observers were instructed to make recognition decisions only when they were almost certain of their decisions, but any errors made could be corrected before the model reached the end of the "flight path." Of the total of 3116 judgments made over all the trials, only 1.2% consisted of uncorrected errors.

Observer Reliability. Reliability is concerned with the consistency of measurement of an event under comparable or repeated conditions. In the context of these tests, reliability refers to the consistency from trial to trial in the recognition ranges obtained by each individual over the set of aircraft. The trial-to-trial reliability coefficients for each view varied considerably, from a low of .11 to a high of .98. Although the trial-to-trial correlations were quite variable, the average reliability coefficient for each observer over all trials was rather high; they ranged from a low of .47 to a high of .84.

For reasons unknown, the majority of the inconsistent observations occurred for the 15° climb- 45° heading view. However, similar analyses performed *across views* showed very few statistically significant correlation coefficients. Although an observer can be acceptably consistent in the range at which he recognizes an aircraft at one aspect angle, he is very inconsistent for different aspect angles. These results suggest that an observer utilizes different cues for different views.

Individual Differences. Correlational analyses were also conducted to evaluate the consistencies between observers in the range at which each aircraft was recognized. The correlation between observer pairs was computed both for the average range at which each aircraft was recognized over all 10 trials for each view and for only the last trial of each view.

The inter-observer correlations for the mean recognition ranges over all trials for each view were quite high, ranging from a low of .43 to a high of .97. Of the set of 36 inter-observer correlations, only the .43 coefficient was not statistically significant. These results suggest that for each view the different observers were using the same cues when making recognition judgments of the aircraft.

CONCLUSIONS

The conclusions reached as a result of the research were as follows:

(1) The recognition ranges obtained in these tests greatly exceed those reported in previous research and are comparable to aircraft *detection* ranges. Since previous tests have used nonvolunteer enlisted personnel as research subjects, the earlier data may not be a valid indicator of the performance levels characteristic of highly trained and well-motivated observers.

(2) The recognition range for an aircraft partly depends upon its overall size, but other factors, perhaps the size of a structural feature, have as great or greater influence on observers' performance.

(3) The area presented by an aircraft at various aspect angles can be accurately estimated from a knowledge of its wing span and length.

(4) The color or reflectance of an aircraft affects the recognition range. Dark-painted aircraft are recognized sooner than aluminum-skinned aircraft.

(5) For any single view of an aircraft, an observer is highly consistent in the relative distances at which various aircraft are recognized. The relative recognition ranges of various aircraft, however, are not consistent across views. It is inferred that the observer searches for recognition cues that are specific to a view, and that different cues are used for different aspect angles.

(6) Observers who have received equal training and experience tend to recognize various aircraft in the same relative distances, suggesting that homogeneously trained observers use the same recognition cues.

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**Relationship Between
Recognition Range and the Size,
Aspect Angle, and Color of Aircraft**

INTRODUCTION

PROBLEM

In February 1971, the U.S. Army Combat Developments Command, Air Defense Agency (USACDCADA) requested that HumRRO Division No. 5 provide information concerning the relationship that tends to exist between the size of an aircraft and the average distance at which it is correctly recognized by a ground observer. Data analogous to that which relates radar detection range to target cross section, as measured by radar reflectivity, was desired.

RESEARCH BACKGROUND

Previous full-scale field tests^{1,2} had provided data concerning the average distance at which a selected few U.S. aircraft were recognized, that is, correctly named (F-100, F-4, etc.). In addition, data were available from a previous HumRRO research effort³ that involved recognition of model aircraft in a reduced-scale experimental simulation of the ground observer's task. However, only a small number of aircraft (either actual or models) had been used in each previous test program, and the testing had not included determinations of the angular aspect presented by the moving targets at the time they were recognized.

For several years USACDCADA had stated a research requirement for additional data concerning aircraft recognition range, and HumRRO had included such a test program as part of Work Unit STAR during FY 1967 and later, in response to the requirement. However, the programmed tests were never accomplished because the extensive air support that was necessarily involved was not available.

The one reduced-scale simulation program that HumRRO previously conducted indicated that valid miniaturization of the recognition task was feasible by using 1/72nd scale models that were transported toward observers at scaled speeds.

TEST PROGRAM CHARACTERISTICS

AIRCRAFT

The test program was designed to provide data for jet-powered attack and fighter-bomber aircraft that would be representative of such aerial targets with respect to size and configuration. The aircraft would have delta, swept back, or straight wings. Both single-engined and multiple-engined aircraft would be included. Aircraft sizes would range between that characteristic of the MiG-15 to that of the B-66.

¹W. Wokoun, *Detection of Random Low Altitude Jet Aircraft by Ground Observers*, U.S. Army Ordnance Human Engineering Laboratories Technical Memorandum 7-60, June 1960.

²A.D. Wright, *The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft*, HumRRO Technical Report 66-19, December 1966.

³Robert D. Baldwin, Edward W. Frederickson, and Edward C. Huckerson, *Aircraft Recognition Performance of Crew Chiefs With and Without Forward Observers*, HumRRO Technical Report 70-12, August 1970.

The aircraft included were selected by the senior researcher from a collection of model aircraft available from previous HumRRD research on aircraft recognition. The final set of aircraft used in the testing were:

- (1) Single-engined: MiG-15, AF-1E, F-84, F-100, Fitter, MiG-21, Mirage, and F-102.
- (2) Multi-engined: B-57, B-66, Flashlight, Firebar, and Beagle.

Views

The selected aircraft were all nominally of 1/72nd scale and would be presented to observers one at a time at fixed aspect angles. The following aspect angles were used:

<u>Climb</u>	<u>Heading</u>
0	0°
10	15°
15	20°
15	45°
45	35°
0	90°

An aircraft with 0° climb--0° heading appears to the observer as head-on; a 0° climb--90° heading presents a side view to the observer.

The model aircraft were painted a dark grey, which had a reflectance of 1000 foot-lamberts when illuminated by natural light outdoors. This level of reflectance is about the same as an aircraft painted with terrain camouflage colors. Since the sky background had a reflectance of approximately 2000 foot-lamberts, the models had an inherent contrast of .50%.

Size

References such as *The Aircraft of the World*⁴ provide measurements of wing span, fuselage length, and height. However, there apparently is no published information that relates the presented area of an aircraft to the climb and heading of the aircraft. In the absence of published data, the following procedure was used to determine the area presented for each of the six aircraft views:

First, the models of the aircraft were photographed for each of the six views, using orthofilm. When projected against the background screen, this film provided sharply delineated contrasts of the aircraft's shape.

Second, the wing span of the actual aircraft was obtained.

Third, each of the six views of the model was projected onto a screen consisting of graph paper. Image size was adjusted so that 1/10th of an inch on the graph paper equaled 1/2 foot of wing span for the actual aircraft. Since the camera-to-model distance had been held constant for the original photography, all six views of an aircraft had a common reference for measurement purposes.

Fourth, for each view, the number of graph paper units (squares) occupied by the aircraft's outline was counted. Since each matrix unit had been adjusted to equal 1/4 foot of area, the total presented area for each view could be computed. These measurements of presented area may only be considered as estimates of the true areas since the

⁴W. Green and G. Pollinger *The Aircraft of the World*, Doubleday and Co., Garden City, New York, 1965.

models used to obtain images may not have been faithful replicas of the actual aircraft. In addition, tracing and minor counting errors undoubtedly occurred. The latter sources of potential error would have only a minor effect on the area measures obtained, because of the scale conversion used (i.e., 1/10th inch equals 1/2 foot).

OBSERVERS

Six "professional" observers served as observers for the tests. A majority of the observations were made by four of the men, the fifth and sixth serving as substitutes. Three of the observers were members of the HumRRO research staff; the other three were college-trained enlisted men assigned to the U.S. Army Air Defense Human Research Unit.

The observers were trained with printed silhouettes, slides, and models of the aircraft, plus approximately eight hours of actual practice in preliminary testing that used the 15° climb-20° heading view. At the termination of training, these observers were performing the recognition task at a very high level of proficiency.

All observers were equipped with 7-power binoculars. Three men used 7x50 binoculars with individually focused eyepieces; the fourth used 7x35 center-focused binoculars.

"Professional" observers were used for this program because of difficulty in obtaining a large sample of well-trained men who would be repeatedly available for the whole test series. The test data obtained, therefore, may not represent how the "typical" soldier assigned as an aircraft observer would perform. At the present time, however, the proficiency of a typical observer apparently is unknown.

FIELD TESTING PROCEDURES

The miniaturized test facility was established on an unused concrete aircraft parking pad at Biggs Army Air Field, adjacent to El Paso, Texas. The observers were located at one end of a scaled 16,000-meter "flight path." The observers were seated on mats placed on the ground and arranged one behind another at an angle of approximately 31° from the end of the flight path.

For the field test, the model aircraft were fixed to a short boom mounted on the roof edge at the side of a panel truck. The truck moved at a scaled speed of 400 knots from a starting position (gate) 15 kilometers (scaled) from the observers. The truck moved along a line passing immediately adjacent to the observers. The view, or aspect of the aircraft presented to the observers, was essentially constant, except for the distances less than 1500 meters, when the vertical angles presented to the observer progressively increased to the point that resulted in a bottom view of the aircraft as it passed over the heads of the observers.

Each observer was provided with a hand-held Reaction Button and a Response Choice Box positioned next to him on the ground. The Reaction Button was depressed at the time a recognition judgment was made. The specific recognition judgment made was subsequently indicated on an event recorder by depressing one of the 13 choice buttons on the Choice Box. (The apparatus used for these decisions is shown in Figure 1.) The four Choice Boxes were connected to a 20-channel event recorder.

Pneumatic switch hoses were positioned every 1000 meters (scaled) along the path of motion of the truck. As the vehicle moved down the "flight path," it actuated each hose successively. These actuations were ticked on one channel of the recorder. Four observer channels monitored the actuation of each observer's Reaction Button and the

Recognition Judgment Apparatus

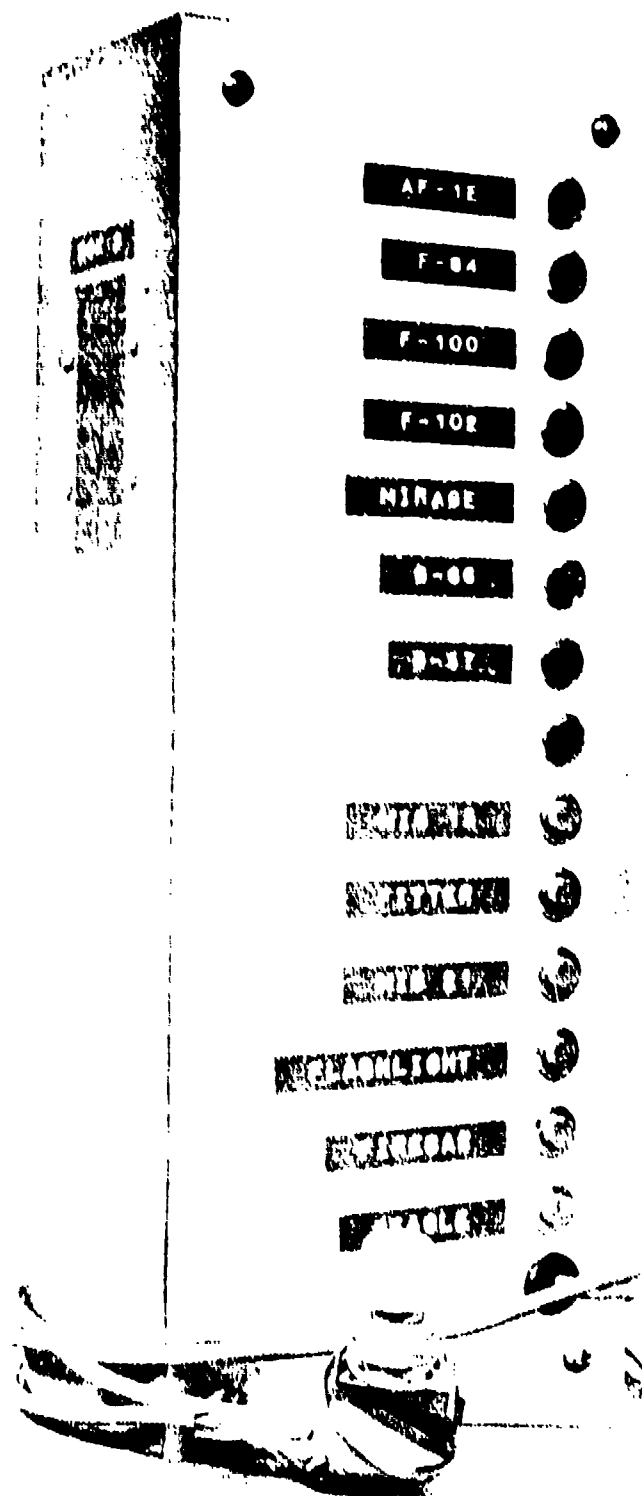


Figure 1

choice events. In addition, 13 additional channels recorded which of the 13 aircraft was designated by each observer.

The aircraft models were mounted on the support boom in a staging area near the starting gate. The models were randomly sequenced in groups of 13 aircraft by means of previously prepared lists. Each aircraft was presented at each aspect 10 times. A total of 40 observer judgments were obtained for each of the six views of each of the 13 aircraft.

The testing was accomplished in one-half day blocks distributed over nine calendar days during the period 23 August through 10 September 1971. The number of lists presented during a block varied between two and five. More lists were presented during each block for the last half of the test program, because all the observers were becoming very proficient and frequently made their judgments shortly after each trial began.

DESCRIPTION OF A TRIAL

The beginning of each trial was announced by the vehicle driver via radio. Upon hearing this signal, each observer placed his binoculars to his eyes and began observation of the aircraft model as the truck moved down the path. When an observer made a judgment, he depressed his Reaction Button, lowered his binoculars, and depressed one of the 13 switches on the Choice Box.

He then was free to rest or to resume observation if he felt less than 100% confident of his recognition judgment. The observers were instructed to continue observation until they were "certain" that they had made a correct judgment. If an observer reversed an earlier decision, he depressed his Reaction Button once again and then made another designation on the Response Choice Box.

When all four observers had discontinued their visual observation of the aircraft model, the event recorder operator "waved off" the truck, which returned to the staging area and prepared for the next trial.

RESULTS

RECOGNITION RANGE

Table 1 presents the mean (average) full-scale distance to the single-engine aircraft at the time the *correct* recognition judgments occurred for each view. The average accuracy of the judgments was 98.8%. Table 2 presents the recognition ranges for the multi-engine aircraft. Each table also includes the average recognition range over the aircraft for each view. The Appendix A table duplicates the averages and includes the standard deviations of the recognition ranges for each aircraft and each view.

The average recognition ranges vary considerably, both within and between the two classes of aircraft and between the aircraft views. For both single- and multi-engine aircraft, the 45° climb-35° heading provides the easiest discrimination. For the single-engine aircraft, the shortest recognition ranges tended to occur most frequently for the 0°-0° view. In contrast, the 15°-45° view was apparently the most difficult discrimination for the multi-engine aircraft.

The mean recognition ranges obtained in this research are much greater than those reported for previous full-scale and miniaturized tests. In a full-scale test involving three aluminum-skinned jet aircraft, Wright⁵ obtained a mean recognition range of 4,320

⁵ Wright, *op cit*.

Table 1
Mean Recognition Range for Eight Single-Engine
Aircraft and Six Aspect Angles
(Meters)

Aircraft	Aspect (Climb-Heading)					
	0°-0°	15°-45°	15°-20°	10°-15°	45°-35°	0°-90°
AF-1E	8,395	8,737	9,686	6,928	9,274	9,779
F-84	7,397	7,786	8,345	9,071	9,154	8,237
F-100	6,679	10,759	10,530	7,582	13,019	11,159
F-102	8,701	12,886	13,638	12,102	14,717	13,545
Mirage	8,031	10,746	12,270	8,256	13,958	10,823
MiG-15	10,755	13,090	11,493	10,403	9,224	11,705
Fitter	6,969	9,501	5,806	5,213	13,272	9,677
MiG-21	7,295	11,836	10,968	9,011	13,168	12,779
Average	7,770	10,668	10,342	8,570	11,970	10,963

Table 2
Mean Recognition Range for Five Multi-Engine
Aircraft and Six Aspect Angles
(Meters)

Aircraft	Aspect (Climb-Heading)					
	0°-0°	15°-45°	15°-20°	10°-15°	45°-35°	0°-90°
B-66	11,448	9,974	13,383	12,900	14,217	12,693
B-57	14,206	13,476	13,632	13,726	14,771	13,908
Flashlight	10,869	8,517	9,376	9,610	12,474	7,731
Firebar	10,442	9,462	12,478	11,105	14,014	11,626
Beagle	11,890	8,665	13,770	12,826	14,631	8,704
Average	11,771	10,019	12,528	12,033	14,021	10,932

meters for observers using 6x30 binoculars. In a miniaturized test involving six aluminum-colored model aircraft, Baldwin *et al.*⁶ obtained a median recognition range of about 5,000 meters for observers using 7x50 binoculars. The fact that the average recognition ranges reported here were similar to the aircraft *detection* ranges reported previously for aluminum-colored aircraft suggested that color or reflectance was a very important factor in determining recognition range.

Additional testing was therefore conducted to evaluate the effect of color (reflectance) on recognition range. The testing was conducted at the same testing facility

⁶ Baldwin *et al.*, *op cit.*

on 19 and 22 November 1971, between 1300-1500 hours. This supplementary test used two sets of model aircraft—one silver-colored and one dark grey. The silver models possessed about the same reflectance as a full-sized aluminum aircraft. The dark grey models were the same color used in the first test program and had a reflectance about the same as an aircraft painted with terrain camouflage colors. All light reflectance measurements were made with a photometer.

There were six models in each color group: AF-1E (F-86), F-100, F-102, Mirage, B-66, and Beagle. These six aircraft were used because duplicate models were available. The model aircraft were presented in a random mixture of aircraft and color. Each model was presented at the 15° climb—45° heading view 10 times in each color. Four of the personnel used earlier served as observers and were equipped with 7-power binoculars.

The average recognition range (scaled-up) in meters for each model and color was as follows:

<u>Aircraft and Color</u>	<u>Average Range, Meters</u>
AF-1E Grey	11,475
AF-1E Silver	8,325
F-100 Grey	10,625
F-100 Silver	8,150
F-102 Grey	12,500
F-102 Silver	9,070
Mirage Grey	9,470
Mirage Silver	7,925
B-66 Grey	11,600
B-66 Silver	10,025
Beagle Grey	8,900
Beagle Silver	10,800

Averaged over all aircraft, the mean for grey was 10,962 meters and for silver was 9,049 meters. With the exception of Beagle, the recognition ranges for the dark grey models were greater than for their silver counterparts. The observers reported that the grey Beagle was very difficult to distinguish from the grey B-66. This discrimination was not so difficult for the silver models of these aircraft.

With the exception of the AF-1E, the recognition ranges obtained for the grey models in the partial replication were similar to the data obtained in the first testing. The data obtained in the partial replication were evaluated by analysis of variance procedures, and the summary is shown in Table 3.

Significant differences in recognition occurred among aircraft, as would be expected. The overall differences between the two colors was also significant, in spite of the significant interaction between color and aircraft. This interaction was due mainly to the inversion of the color effects for Beagle.

The obtained recognition ranges for the silver models still exceed the average ranges reported for previous tests. It is assumed that the "professional" observers used in this most recent test had higher proficiency levels than may have been characteristic of the nonvolunteer subjects used in previous research.

RECOGNITION ACCURACY

The observers' accuracy in their recognition judgments was computed for each view separately. A response was considered an error if an erroneous judgment was uncorrected

Table 3
Analysis of Variance Summary Table for
Partial Replication

Source	df	Mean Square	F	p
Between Aircraft (A)	5	532	4.51	.01
A x Subject Error	15	118		
Between Colors (C)	1	3519	15.71	.05
C x Subject Error	3	224		
A x C	5	747	7.70	.01
A x C x Subject Error	15	97		
Between Subjects	3	2574		

before the model reached the termination of the "flight path." The percentage of erroneous judgments for each view was as follows:

View	Percent Errors
0° - 0°	2.7
10° - 15°	0.2
15° - 20°	0.8
15° - 45°	1.0
45° - 35°	0.8
0° - 90°	1.6

Since an approximate total of 520 judgments were made for each view, these very low error rates indicate that the observers were not taking risks in making their decisions. For the total group of 3,116 observations, only 1.2% contained uncorrected errors.

RECOGNITION THRESHOLD

The major objective of this research was to determine the magnitude of the visual solid angle subtended by the aircraft at the mean (average) recognition range. However, since aircraft have an irregular form, it is not possible to compute a corresponding solid angle. Instead, an approximation method was employed. The diameter of a circle having an area equal to that presented by each aircraft-view combination was determined. The angle subtended at the eye by this diameter at the average recognition range then was computed for each aircraft and view. The subtended solid angle is the square of this visual angle. This geometric approximation to the visual shape of an aircraft in the frontal-parallel plane seems apropos for all the aspect angles used except the 0° climb-90° heading.⁷

Table 4 presents the solid angle equivalent area circles for each aircraft and view at the average distance at which it was correctly recognized. The solid angles are expressed in terms of square mils of solid angle rounded to the nearest whole mil.⁸ Although these

⁷ A rectangle having a length equal to that of the fuselage and a height adjusted to provide an area equivalent to that of the aircraft would have provided a better practical approximation. Such rectangular equivalents, however, were not computed for the 0°-90° view. All geometrical approximations used circles of equivalent area for the purpose of consistency.

⁸ Expression of the size of the aircraft in geometric terms may be of value for operations analysis procedures involving gaming and computer simulations of air defense actions.

Table 4
Aircraft Size in Square Mils at the
Mean Recognition Range

Aircraft	Aspect (Climb-Heading)					
	0°-0°	15°-45°	15°-20°	10°-15°	45°-35°	0°-90°
AF-1E	10	29	26	39	46	28
F-84	13	34	28	16	42	41
F-100	18	26	27	36	31	30
F-102	16	24	29	29	41	38
Mirage	14	20	14	18	19	24
MiG-15	6	9	12	13	17	16
Fitter	12	21	46	41	34	28
MiG-21	9	16	16	16	22	21
B-66	21	43	36	30	54	45
B-57	10	21	32	19	45	23
Flashlight	7	35	27	18	28	46
Firebar	12	37	20	17	31	31
Beagle	12	45	24	18	39	60

solid angles are frequently quite small, it should be recalled that the task involved the use of 7-power binoculars as a recognition aid.

AIRCRAFT SIZE

The cross-sectional area of each aircraft in the frontal-parallel plane was estimated by the method discussed earlier, for each of the six aspect angles or views. Table 5 presents these data, along with the wing span, fuselage length, and gross weight.

Since the method of estimating the presented area of an aircraft was so laborious, there was interest in evaluating a correlational procedure for estimating area from other physical measurements of the aircraft. Accordingly, Pearson product-moment correlation coefficients were computed to estimate the strength of the relationships among presented area and span, length, and weight. These correlations are presented in Table 6.

The correlations between pairs of predictor variables were as follows:

Span and weight = .91.

Span and length = .78.

Weight and length = .83.

Multiple regression correlation coefficients were also computed, to predict area from two variables concurrently. Table 7 presents the multiple regression coefficients. Inspection of Table 7 indicated that the combination of either length and weight or length and span accounted for a majority of the predictable variance in area measurements. The configuration of wing span and weight did not appear to be as effective in the prediction of area.

The set of multiple regression equations to predict the presented area (A) for each of the six angles from span (S) and length (L) measurements is as follows:

(1) 0°-0° Heading: $A = 2.8S + 1.7L - 117.0$

(2) 0°-90° Heading: $A = 2.2S + 9.4L - 238.2$

(3) 10°-15° Heading: $A = 2.7S + 5.6L - 208.0$

Table 5

Square Feet of Area Presented by Aircraft at Six Aspect Angles

Aircraft	Wing Span (Ft.)	Length (Ft.)	Weight (x 1000) (lbs.)	Aspect (Climb-Heading)					
				0°-0°	15°-45°	15°-20°	10°-15°	45°-35°	0°-90°
AF-1E	39	36	28	60	197	208	162	351	228
F-84	34	43	28	58	180	166	109	309	246
F-100	38	47	28	68	220	256	179	453	316
F-102	38	68	27	103	447	468	366	781	606
Mirage	27	51	29	42	195	182	101	317	236
MiG-15	33	36	14	54	147	127	114	252	188
Fitter	32	50	29	48	176	136	98	248	220
MiG-21	25	40	17	38	185	165	112	318	293
B-66	72	75	78	236	542	567	436	976	634
B-57	64	66	50	168	371	506	296	872	376
Flashlight	36	55	30	67	178	201	141	367	240
Firebar	40	55	30	107	285	262	179	530	363
Beagle	68	62	44	137	371	380	247	721	408

Table 6

Correlations Between Aircraft Area and Physical Dimensions

Aspect Angle	Wing Span	Fuselage Length	Gross Weight
0°-0°	.93	.86	.94
15°-45°	.84	.91	.86
15°-20°	.87	.91	.85
10°-15°	.83	.88	.83
45°-35°	.89	.90	.86
0°-90°	.73	.86	.77

Table 7

Multiple Regression Coefficients for Area and Pairs of Predictors

Aspect Angle	Span and Weight	Span and Length	Weight and Length
0°-0°	.97	.96	.96
15°-45°	.88	.93	.91
15°-20°	.89	.95	.93
10°-15°	.85	.90	.90
45°-35°	.90	.95	.93
0°-90°	.78	.85	.87

$$(4) 15^\circ-20^\circ \text{ Heading: } A = 4.2S + 7.5L - 284.6$$

$$(5) 45^\circ-35^\circ \text{ Heading: } A = 8.3S + 12.1L - 475.3$$

$$(6) 15^\circ-45^\circ \text{ Heading: } A = 3.1S + 7.2L - 233.2$$

The aircraft included in the sample used to determine these regression equations are believed to be representative of the larger population of attack and fighter-bomber aircraft. As a result, these regression equations should provide valid estimations of the presented areas for aircraft not included in the experimental sample.

PREDICTING RECOGNITION RANGE

The relationship between mean recognition range and aircraft size was evaluated via correlational procedures. Pearson product-moment correlation coefficients were computed to determine the strength of the covariation between the average recognition ranges and

the presented areas of the 13 aircraft for each of the six aspect angles. The obtained correlations are presented in Table 8.

Table 8
Correlations Between Average
Recognition Ranges and
Aircraft Areas

Aspect Angle	Correlation ^a
0°-0°	.72
15°-45°	.18
15°-20°	.72
10°-15°	.74
45°-35°	.64
0°-90°	.53

^aA coefficient of .55 is required
for statistical significance at the .05 level.

As indicated by the size of the obtained coefficients, between 25 to 50% of the variability in recognition range can be predicted from a knowledge of aircraft size for five of the views. Apparently, the presented area of the whole aircraft is not the exclusive determinant of the time when the recognition judgment occurs. The correlation for the 15°-45° view was unusually low (.18) in comparison with the ranges for the other views. As previously mentioned, this view appeared to offer the greatest difficulty of all the views of the multi-engine aircraft. In an effort to explain this, analyses were made of the individual observer's trial-to-trial reliability.

OBSERVER RELIABILITY

Reliability is concerned with the consistency or repeatability of measurements obtained under specific conditions. In the recognition tests reported, observers made judgments about an aircraft's name as it was moved toward them. If the recognition judgment was related to some size-associated factor, it would be expected that each specific aircraft view would elicit a correct judgment when the aircraft reached some more-or-less constant distance. The constant distance, however, would vary among the aircraft in a set, because of initial size differences among the aircraft. In the context of this task, therefore, reliability refers to the consistency from trial to trial of each observer's recognition range for each aircraft. The reliability of each observer's judgment was estimated by computing the correlation of the aircraft recognition ranges for successive pairs of trial blocks (trial block 1 versus 2, 2 versus 3, etc.). A trial block was defined as the presentation of the set of 13 aircraft. These computations were made for each separate observer-view combination. For each such combination, nine correlation coefficients were computed.

The 216 reliability coefficients ranged in magnitude from a low of 0.11 to a high of 0.98. The average reliability for each observer-view combination was computed, using the *r*-to-*z* transformation method of averaging correlation coefficients. The mean reliability coefficients are presented in Table 9.

All the average coefficients, except two, are statistically reliable at the .05 level of confidence. The two low coefficients are those obtained by Observers 3 and 4 for the

Table 9

**Average Reliability Coefficients for
Each Observer and View Combination**

Aircraft View	Observer Number			
	1	2	3	4
0°-0°	.83	.63	.80	.72
15°-45°	.65	.67	.53	.47
15°-20°	.79	.81	.83	.84
10°-15°	.82	.73	.64	.77
45°-35°	.84	.71	.77	.65
0°-90°	.78	.63	.64	.81

15°-45° view. The percentage of statistically significant reliability coefficients was also determined for each view summed over the four observers. The results were as follows:

View	Percent of 36 Coefficients
0°-0°	86
0°-90°	78
10°-15°	78
15°-20°	92
45°-35°	83
15°-45°	47

It is evident from these results that there was a notable absence of trial-to-trial consistency in the judgments made by all four observers for the 15°-45° view. In fact, the lowest reliability coefficient, 0.11, was obtained by Observer 2 for trial blocks one and two of this view. The lack of reliability for this view cannot be attributed to climatic or environmental variation since the day was bright and cloudless. The causes of inconsistency in the judgments of this aircraft view are unknown at present.

CONSISTENCY ACROSS VIEWS

A second facet of reliability is the consistency of the recognition ranges obtained between pairs of aircraft views. Estimates of this form of judgmental consistency were obtained by correlating the average recognition ranges for all pairs of views—for example, 0°-0° versus 0°-90°. The obtained correlations for the average ranges across all observers and trials are presented in Table 10.

Relatively few of the intercorrelations were statistically reliable. The pairs of views in this category were the following:

- 0°-0° versus 10°-15° and 0°-0° versus 15°-20°
- 10°-15° versus 15°-20°
- 15°-45° versus 0°-90°
- 0°-90° versus 15°-20°

From these results, it was inferred that these pairs of views are highly similar with respect to the recognition features that become discriminable at various distances.

Additional correlational analyses were made for each individual observer. The intercorrelations between ordinal pairs of trials for all combinations of two views were

Table 10
Correlations Between Average
Recognition Ranges for
Pairs of Views

View Pair	r^a
0°-0° vs. 10°-15°	.81*
15°-20°	.55*
15°-45°	.21
45°-35°	.25
0°-90°	.22
15°-45° vs. 10°-15°	.44
15°-20°	.47
45°-35°	.26
0°-90°	.85*
15°-20° vs. 45°-35°	.53
10°-15° vs. 15°-20°	.85*
45°-35°	.45
0°-90° vs. 10°-15°	.44
15°-20°	.58*
45°-35°	.43

^aStatistically significant at .05 level.

computed—for example, trial one of 10°-15° versus trial one of 0°-90° for Observer 2. The 450 trial-by-trial intercorrelations are presented in Table 11 for each observer and each pair of views. (Portions of the trial data had to be dropped from this analysis because, since observer replacements occurred from day to day, some of the observers did not participate in the trials for some views.) The objective of this analysis was to determine the consistency *within* the individual observer with respect to the inter-view, rather than intra-view, variability in recognition ranges.

With a few notable exceptions, inspection of the matrix of intercorrelations for each view pair showed a really surprising lack of consistency. The majority of the intercorrelations were not statistically reliable. The notable exceptions were the matrix for 0°-0° versus 10°-15°, and the matrix for 10°-15° versus 15°-20°. These results support the correlational analysis accomplished on the average recognition ranges.

INDIVIDUAL DIFFERENCES

Since the variation in average recognition range between views also could be a function of judgmental differences *between observers*, correlation analysis was also conducted on inter-observer differences in the recognition ranges of the 13 aircraft. For this analysis, only the recognition range data obtained on the 10th (last) trial block for each view were used. The intercorrelations in the recognition ranges for the aircraft between each pair of observers were computed. These intercorrelations are shown in Table 12. Each correlation coefficient is a measure of the extent to which a pair of observers tended to recognize each of the aircraft at the same distance. Low

Table 11

Trial-by-Trial Intercorrelations for Each Observer and Pair of Views

View Pair	Observer Number	Trial Number									
		1	2	3	4	5	6	7	8	9	10
0°-0° vs. 10°-15°	1	.73	.36	.82	.61	.64	.61	.62	.68	.72	.73
	3	.40	.30	.48	.15	.80	.77	.44	.44	.71	.32
	4	.65	.46	.48	.53	.76	.61	.70	.78	.86	.68
0°-0° vs. 15°-20°	1	.64	.29	.66	.10	.29	.19	.71	.26	.75	.64
	2	.64	.19	.63	.13	.03	.47	.13	.42	.43	.20
	3	.68	.38	.68	.30	.43	.49	.42	.27	.28	.31
	4	.42	.18	.44	.42	.36	.48	.52	.45	.53	.66
0°-0° vs. 15°-45°	1	.05	.10	-.07	.30	.45	.07	-.03	-.25	-.05	-.05
	3	.47	.21	.59	.40	.35	Changed Observers				
	4	.18	-.01	.20	.65	.76	.71	.36	-.02	.09	.67
0°-0° vs. 45°-35°	1	.31	.26	.31	.04	.44	.17	.48	.03	.23	.24
	2	.56	.44	.48	-.25	-.08	.06	-.33	.06	.30	.12
	4	.11	-.03	-.01	.07	-.21	.48	.00	.26	.49	.37
0°-0° vs. 0°-90°	1	.61	-.20	.41	.06	.20	.10	.48	.22	.35	.48
	3	.78	-.26	.45	.02	.05	-.20	.38	-.34	-.26	.04
	4	.70	.06	.79	.04	.40	.35	.14	-.34	.30	.13
15°-45° vs. 10°-15°	1	-.26	.42	.19	.12	.25	-.26	.01	.00	.21	.08
	2	-.10	.17	.33	.07	.39	-.08	.14	-.12	.30	.40
	3	.23	.43	.13	.48	.48	Changed Observers				
	4	.01	.20	.05	.33	.67	.20	.06	.17	-.01	.70
15°-45° vs. 15°-20°	1	-.29	.61	-.10	.55	.57	-.09	-.09	.11	.12	.11
	2	.22	.40	.35	.67	.66	Changed Observers				
	3	Changed Observers					.21	.71	.66	.28	.60
	4	.11	.29	-.09	.41	ND	.54	.17	.61	.22	.52
15°-45° vs. 45°-35°	1	.00	.34	-.19	.16	.55	-.10	.14	.20	.30	-.21
	3	Changed Observers					-.12	.10	.53	.14	.55
	4	-.20	-.01	-.08	.01	.20	.45	.04	.57	.22	.79
15°-45° vs. 0°-90°	1	.28	.39	.18	.71	.64	.34	.35	.41	.13	.32
	2	.28	.10	.45	.60	.39	.40	.48	.3458
	3	.45	.09	.26	.57	.76	Changed Observers				
	4	.46	.57	.56	.36	.60	.69	.44	.59	.51	.20
15°-20° vs. 45°-35°	1	.23	.84	.72	.59	.56	.58	.57	.64	.39	.48
	2	.38	.67	.34	.12	.29	.73	.33	.39	.42	.26
	4	.50	.61	.46	.47	ND	.56	.29	.52	.63	.22
10°-15° vs. 15°-20°	1	.79	.81	.41	.38	.43	.40	.65	.67	.86	.48
	3	.48	.63	.66	.52	.51	.67	.41	.76	.71	.49
	4	.79	.60	.79	.36	.58	.80	.65	.46	.70	.80
10°-15° vs. 45°-35°	1	.32	.66	.27	.48	.17	.28	.08	.49	.38	.32
	4	.70	.48	.38	-.09	.03	.21	.04	.26	.36	.34

(Continued)

Table 11 (Continued)

Trial-by-Trial Intercorrelations for Each Observer and Pair of Views

View Pair	Observer Number	Trial Number									
		1	2	3	4	5	6	7	8	9	10
0°-90° vs. 10°-15°	1	.27	.36	.44	.10	.31	.29	.29	.62	.54	.17
	2	.72	.37	.41	.13	.07	.02	-.02	.35	-.35	.19
	3	.73	.57	.79	.23	.36	.15	.42	.10	.05	.58
	4	.49	.62	.10	.02	.13	.08	-.17	-.07	-.02	.10
0°-90° vs. 15°-20°	1	.17	.28	.66	.46	.32	.42	.65	.75	.52	.49
	3	.70	.54	.49	.39	.51	.28	.66	.40	.43	.21
	4	.42	.58	.22	.32	ND	.56	.38	.17	.52	.08
0°-90° vs. 45°-35°	1	.44	.34	.67	.38	.46	.64	.66	.52	.79	.53
	4	.15	.42	.28	.03	.29	.51	.21	.14	.49	.02

Table 12

Intercorrelations of Recognition Ranges Between Pairs of Observers for Each View on Trial 10

Aircraft View	Observer Pairs						Mean r
	1 and 2	1 and 3	1 and 4	2 and 3	2 and 4	3 and 4	
0°-0°	.48	.63	.67	.73	.25	.34	.60
15°-45°	.51	.48	.20	.75	.71	.74	.59
15°-20°	.52	.61	.86	.75	.68	.67	.70
10°-15°	.86	.83	.62	.77	.62	.76	.78
45°-35°	.90	.96	.93	.93	.87	.97	.93
0°-90°	.74	.82	.62	.56	.55	.80	.71

intercorrelations suggest that the different observers were using different recognition cues. High correlations suggest that the observers were using the same recognition cues and were able to discriminate these features at nearly the same distance.

Summed over observer pairs, the set of lowest intercorrelations obtained was associated with the 0°-0° view. The highest set of intercorrelations occurred for the 45°-35° view. These results support the analysis of the average recognition range, which indicated that the easiest view to discriminate was 45°-35°, and one of the most difficult views was 0°-0°.

Table 12 also presents the average intercorrelation for each view. These average r s reflect the overall variability in the recognition ranges of the set of observations for each view. Again, the 45°-35° view had the greatest inter-observer consistency and the 15°-45° and 0°-0° observations the least. From inspection of the pattern of intercorrelations, Observer 1 tended to be different from all others for the 15°-45° view; this was true for Observer 4 for the 0°-0° view.

Table 12 presents the inter-observer correlations for the 10th trial for each view. This trial was selected on the assumption that each observer's performance level would be relatively stable by the 10th trial. To check this assumption, the average range at which each of the observers recognized each aircraft view was computed. The inter-observer correlations were again determined, using the average ranges rather than the score, for only the 10th trial. This set of intercorrelations is presented in Table 13.

Table 13
**Intercorrelation of Recognition Ranges
Between Pairs of Observers:
Mean Recognition Range per Individual**

Aircraft View	Observer Pairs					
	1 and 2	1 and 3	1 and 4	2 and 3	2 and 4	3 and 4
0° - 0°	.88	.78	.84	.85	.85	.86
15° - 45°	.84	.83	.79	.88	.80	.81
15° - 20°	.76	.89	.89	.86	.89	.82
10° - 15°	.87	.43	.90	.76	.81	.91
45° - 35°	.96	.97	.89	.97	.88	.89
0° - 90°	.75	.77	.91	.92	.81	.71

This matrix of intercorrelations displays much less fluctuation than characterized data in Table 12. In addition, the magnitudes of the intercorrelations are higher in Table 13 than in Table 12. Only one of the coefficients in Table 13 was not statistically reliable--that for the data from Observers 1 and 3 for the 10°--15° view.

These results suggest that even the highly practiced observers displayed moderate to considerable individual differences on any *single* trial, but their *overall* or average performance levels in recognizing the various aircraft were comparable. This also suggests that it would be a somewhat unsuccessful venture to attempt an accurate prediction of the recognition range of a specific aircraft by a specific individual on a specific trial. However, predicting what will occur *on the average* can be done with considerable accuracy.

Appendix A
RECOGNITION RANGE TABLE

Table A-1
Mean (\bar{X}) and Standard Deviation (σ) of Recognition Ranges^a
(Meters)

Aspect	Aircraft	\bar{X}	σ	Aspect	Aircraft	\bar{X}	σ
0°-0°	AF-1E	8,390	2,860	10°-15°	AF-1E	8,928	2,612
	F-84	7,399	2,382		F-84	9,071	2,402
	F-100	6,679	2,043		F-100	7,582	2,381
	F-102	8,701	2,838		F-102	12,102	2,089
	Mirage	6,031	1,941		Mirage	8,256	2,197
	MiG-15	10,744	1,806		MiG-15	10,404	2,017
	Fitter	6,959	1,810		Fitter	5,213	2,818
	MiG-21	7,295	2,994		MiG-21	9,011	2,161
	B-66	11,448	1,919		B-66	12,900	1,247
	B-57	14,206	595		B-57	13,726	945
	Flashlight	10,869	1,551		Flashlight	9,610	2,269
	Firebar	10,442	2,027		Firebar	11,105	2,780
	Beagle	11,890	1,816		Beagle	12,826	2,027
0°-90°	AF-1E	9,779	3,617	15°-20°	AF-1E	9,686	2,426
	F-84	8,238	3,067		F-84	8,385	2,088
	F-100	11,159	1,958		F-100	10,530	2,188
	F-102	13,545	849		F-102	13,638	944
	Mirage	10,823	2,940		Mirage	12,270	1,252
	MiG-15	11,705	1,839		MiG-15	11,493	1,700
	Fitter	9,676	3,424		Fitter	5,806	3,305
	MiG-21	12,779	1,693		MiG-21	10,968	2,580
	B-66	12,694	1,307		B-66	13,383	988
	B-57	13,908	528		B-57	13,632	891
	Flashlight	7,731	2,870		Flashlight	9,376	2,657
	Firebar	11,626	2,169		Firebar	12,478	2,290
	Beagle	8,703	3,387		Beagle	13,770	1,112
45°-35°	AF-1E	9,274	2,945	15°-45°	AF-1E	8,737	2,398
	F-84	9,154	2,412		F-84	7,786	2,828
	F-100	13,018	2,220		F-100	10,758	2,164
	F-102	14,716	321		F-102	12,886	2,590
	Mirage	13,958	1,076		Mirage	10,746	2,407
	MiG-15	9,223	3,092		MiG-15	13,090	1,503
	Fitter	13,272	1,735		Fitter	9,501	1,979
	MiG-21	13,168	3,123		MiG-21	11,836	2,015
	B-66	14,218	939		B-66	9,974	3,445
	B-57	14,771	295		B-57	13,476	1,795
	Flashlight	12,474	1,967		Flashlight	8,518	1,827
	Firebar	14,013	517		Firebar	9,462	1,951
	Beagle	14,631	403		Beagle	8,665	3,278

^aDuplicates the average recognition ranges and includes the standard deviations of the recognition ranges for each aircraft and each view.

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